TENSILE BEHAVIOR OF FUNCTIONALIZED GRAPHENE - EPOXY NANOCOMPOSITES

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ABSTRACT

Graphene and its composites are rising high technological materials. However, several challenges, including agglomeration and weak interfacial interactions, still need to be addressed. These issues can be solved by selecting proper the dispersion method and the functionalization of graphene. In this work, the mechanical properties of the nanocomposites composed of 0.1 wt% functionalized graphenes (f-GNFs) and epoxy resin under the tensile load are studied. The graphene is functionalized with Triton X-100 surfactant and mechanically dispersed by using three roll milling (3RM). Compared to the neat epoxy, the f-GNFs reinforced nanocomposites are less stiff (-7.25%), more ductile (+30.82%), and stronger (+19.03%) under quasi-static tensile testing.

Keywords: graphene; functionalizing; three roll milling.

INTRODUCTION

Graphene is the strongest material in the world. The tensile strength of pristine graphene (without any defect, pure graphene) is 130 GPa and the elasticity modulus is 1 TPa [1]. Graphene can be inspected using X-ray diffraction, scanning, tunneling microscopy, Raman spectroscopy, transmission electron microscopy (TEM), and atomic force microscopy.

The nanoparticle's cohesion significantly rises as the particle's surface energy increases due to the nano size effect. However, cohesion diminishes the nanoparticle's ease of handling. An effective approach to enhance the handling properties of nanoparticles involves implementing composite structures with the help of surface modification. Nanocomposite applications allow to control of surface modification and thus cohesion. As a result, four physical properties can be used to determine a polymer nanocomposite: dispersibility, cohesive property, porosity, and compact density [2, 3, 4].

In this study, the functionalized graphene epoxy nanocomposites are manufactured by using three roll milling. Then, the mechanical properties of the nanocomposites composed of 0.1 wt% functionalized graphenes (f-GNFs) and epoxy resin under the tensile load are investigated.

FUNCTIONALIZED GRAPHENE REINFORCED EPOXY NANOCOMPOSITES: FABRICATION

Materials and Geometry: The nanocomposite specimens consist of two components: functionalized graphene nanoflakes (f-GNFs), and epoxy resin (Fibermak F-1564). The epoxy resin is cured with hardener (Fibermak F-3487). The graphene nanoflakes are synthesized via the electrical discharge method. Raman spectroscopy analysis of the collected graphene revealed that the nanoflakes are composed of 4 to 5 layers [4]. The graphene-to-matrix (epoxy + hardener) weight ratio is maintained at 0.1 wt.%.

Fabrication of the Functionalized Graphene (f-GNF) and Functionalized Graphene-Epoxy Nanocomposite: Functionalization is one of the important methods for preventing agglomeration and enhancing interfacial adhesion. Triton X-100 surfactant was used as a treatment. The functionalization steps are as follows: Triton X-100 surfactant was mixed with distilled water and graphene. The mixture was sonicated for 45 minutes at 60°C. After sonication, the mixture was stirred using a magnetic stirrer for 12 hours at 65°C. During this 12-hour stirring period, graphene was functionalized. Filtration was carried out using a vacuum filter for 12 hours. Following filtration, the functionalized graphene nanoflakes (f-GNFs) were dried in an oven at 60°C [5].

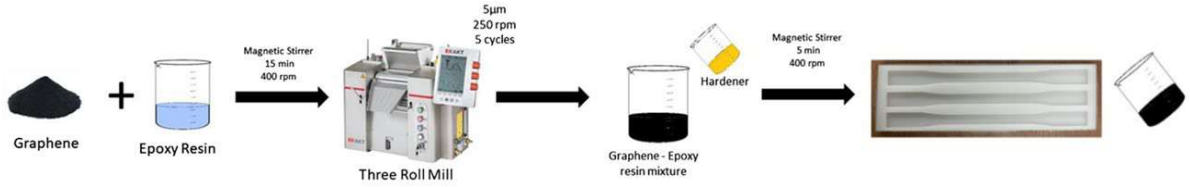


Figure 1. Manufacturing steps of f-GNF nanocomposite [6]

The preparation of the nanocomposite specimens was conducted as follows (Figure 1): The required amount of epoxy was measured and mixed with 0.1 wt.% f-GNFs in a beaker. The mixture was stirred at 400 rpm and 60°C for 15 minutes. Mechanical dispersion was performed using an EXAKT 80S Plus 3RM. High mechanical shear forces generated by the relative motion of the rolls facilitated the dispersion of f-GNFs into the epoxy matrix with minimal agglomeration (Figure 2). The device was set to a roll gap of 5 micrometers and operated at 250 rpm, with the process repeated for 5 cycles. The hardener was added to the nanocomposite mixture, with its amount calculated as 34 wt.% of the epoxy according to the Fibermak manual. The mixture containing the hardener was stirred at 400 rpm for 5 minutes using a magnetic stirrer. The uncured nanocomposite was poured into a silicone mold and allowed to be cured at room temperature for two days. Additionally, a neat epoxy specimen was prepared by pouring pure epoxy into the mold simultaneously with the nanocomposite specimens and curing it under the same conditions for two days.

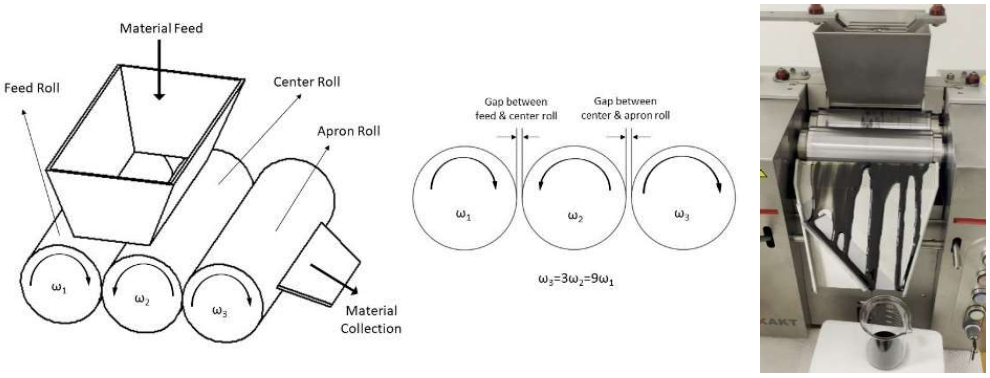


Figure 2. Schematic display of the three-roll mill device and velocity relation of the milling cylinders and three roll milling of the f-GNFs and epoxy.

RESULTS AND DISCUSSIONS

Tensile tests were done with the MTS Static Material Test Machine according to ASTM D638-22 standards [6]. For each material, four samples were subjected to test. In Figure 3, tensile test results of the neat epoxies can be seen. Average values with the standard deviations are: Ultimate strength is 42.16±7.23 MPa, fracture elongation (%) is 1.76±0.31, and elasticity modulus is 2457.98±84.97 MPa.

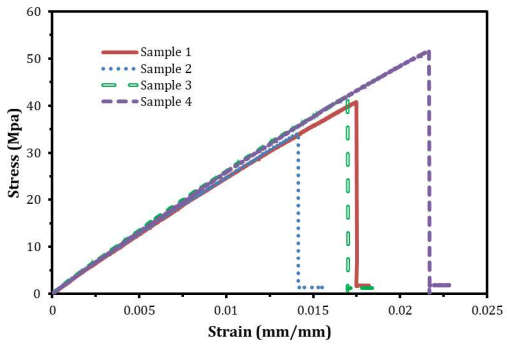


Figure 3. True tensile stress - strain curves of the neat epoxy samples.

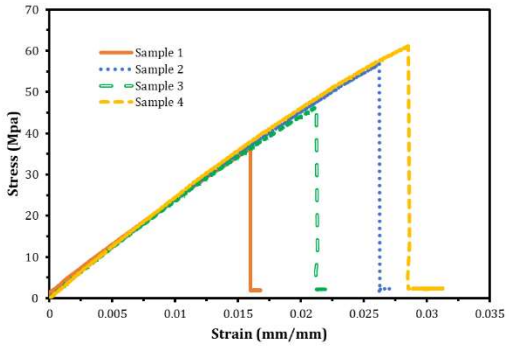


Figure 4. True tensile stress - strain curves of the epoxy + 0.1 wt.% f-GNFs nanocomposite samples.

Functionalized graphene nanoflakes reinforced epoxy samples' tensile values are shown in Figure 4. Average values with the standard deviations are: Ultimate strength is 50.18±11.09 MPa, fracture elongation (%) is 2.3±0.56, and elasticity modulus is 2279.65±70.06 MPa. Polymer and polymer nanocomposite samples' appearances after the tensile tests are shown in Figure 5.

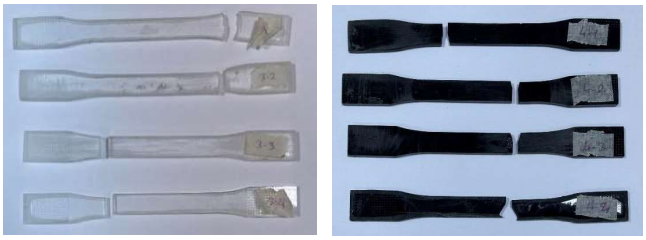
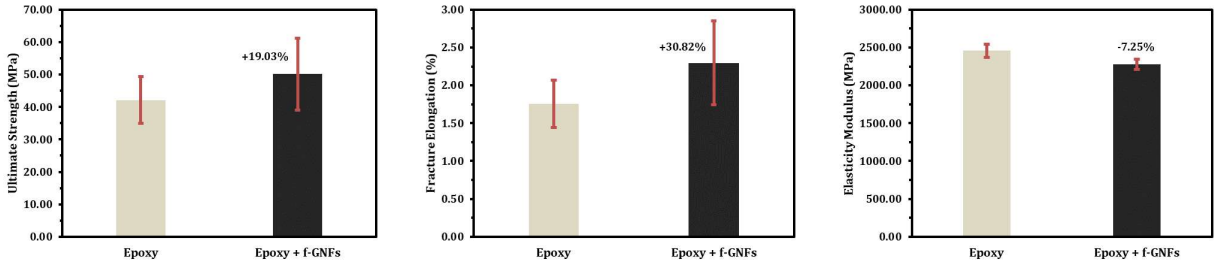


Figure 5. Samples after the tensile test: Neat epoxy and epoxy + 0.1 wt.% f-GNFs nanocomposite.

For easier comparisons, Figures 6a, b, c are created. These graphs demonstrate the property differences between compared materials. According to the results, f-GNFs make the epoxy less stiff (less elasticity modulus), more ductile (higher fracture elongation), and stronger (higher ultimate strength).



a) b) c)

Figure 6. a) ultimate strength, b) fracture elongation, and c) elasticity modulus comparisons of the neat and epoxy + 0.1 wt.% f-GNFs.

Graphene-epoxy interfacial adhesion was improved with the functionalizing. Also, three roll milling dispersed the functionalized graphene into the epoxy matrix without agglomeration. Ultimate strength enhanced by stress transfer to the graphene and crack bridging. f-GNFs showed a decreased effect on the elasticity modulus of the nanocomposite. The probable cause is the usage out of date epoxy. It becomes more brittle as other out of date (almost 8 months) thermosetting polymers.

CONCLUSIONS

Functionalized graphene reinforced epoxy nanocomposites are prepared for 0.1 wt.% graphene fraction. 3RM is used as the main strategy for a homogeneous dispersion of graphene in the epoxy matrix. Functionalization of GNFs using Triton X-100 as a surfactant is performed to improve the interfacial bonding between matrix and graphene, and also to prevent agglomeration. The produced nanocomposites are subjected to tensile tests at a quasi-static strain rate. It is observed that ultimate strength (19.03%) and fracture elongation (30.82%) are improved while elasticity modulus decreases (-7.25%).

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